THE EFFECT OF THE PALM OIL FUEL ASH (POFA) AS CEMENT REPLACEMENT ON HIGH PERFORMANCE CONCRETE (HPC)

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ABSTRACT

Palm Oil Fuel Ash (POFA) is a by-product of the burning of fiber and shell which are used, as fuel to generate steam and energy required for the operation of mill. It has been used as partial cement replacement for normal concrete, high strength concrete, high performance concrete and aerated concrete. For this research, the effectiveness of POFA as a partial cement replacement in High Performance Concrete (HPC) in term of strength, water absorption and corrosion resistance was investigated. HPC is replaced by weight with 10%, 20% and 30% of POFA. For compression and water absorption testing, a cube sample with dimension 150mm X 150mm X 150mm is used whereas for the corrosion resistance test, the specimen is prepared in a cylinder form with diameter of 80mm and 160mm in height. The specimens are cure using water curing for 7, 28 and 90 days. From the testing carried out, it is found that the compressive strength of HPC with 20% of POFA achieve the highest compressive strength compared to other mix. For the water absorption test, the results shows that HPC with 20% of POFA have a lowest percentage of water absorption compared to other mix. The Half-cell potential results for corrosion also show the same outcome as compressive and water absorption test which is POFA with 20% have a lowest corrosion reading compared to other mix. As a conclusion, it is found that replacement of POFA will enhance the strength and durability of HPC with optimum replacement is 20%.

ABSTRAK

Abu kelapasawit (POFA) merupakan produk hasil pembakaran fiber dan tempurung kelapa sawit yang digunakan bagi menjanakuasa untuk operasi kilang kelapa sawit. POFA telah digunakan sebagai bahan separa ganti simen untuk konkrit normal, konkrit berudara, konkrit berkekuatan tinggi dan konkrit prestasi tinggi. Untuk kajian ini, keberkesanan POFA sebagai bahan separa ganti simen dalam konkrit prestasi tinggi dari aspek kekuatan, penyerapan air dan rintangan karatan telah dijalankan. Simen di dalam konkrit prestasi tinggi (HPC) telah digantikan dengan 10%, 20% dan 30% POFA. Bagi ujian mampatan dan penyerapan air, sampel kiub berdimensi 150mm x 150mm x 150mm telah digunakan manakala bagi ujian rintangan karatan, sampel telah dibuat dalam bentuk silinder dengan diameter 80mm dan ketinggian 160mm. Semua sampel telah diawetkan didalam air selama 7, 28, dan 90 hari. Berdasarkan dari ujikaji yang telah dijalankan, didapati bahawa kekuatan bagi HPC dengan 20% POFA mencapai kekuatan tertinggi berbanding dengan bancuhan lain. Bagi ujian penyerapan air, hasil menunjukkan bahawa HPC yang mengandungi 20% POFA mengalami peratusan penyerapan air yang paling sedikit berbanding sampel lain. Hasil dari ujian rintangan karatan dengan menggunakan ujian keupayaan sel-separuh menunjukkan HPC mengandungi 20% POFA memiliki bacaan rintangan karatan yang rendah berbanding sampel lain. Kesimpulannya, didapati bahawa penggantian separa simen dengan POFA dalam HPC akan meningkatkan kekuatan dan ketahanan HPC dengan jumlah penggantian yang optimum sebanyak 20%.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

From the Principals Statistic of Oil Palm Estates (1974 – 2010), Malaysia issued by Malaysian Palm Oil Board (MPOB), there are significant increment of production of fresh fruit bunches from year 1974 until 2010. Up to 2010, Malaysia produces 64, 282, 738 tonnes of fresh fruit bunches which is 15 times higher compared to year 1974 where Malaysia only produce 4, 152, 843 tonnes of fresh fruit bunches per year. The crude palm oil production increment is slightly the same with the production of the fresh fruit bunches.

Today, the palm oil production is one of the important sectors to be developed commercially in Asian region. Malaysia is now currently become a number one palm oil producer and forecasting in the world *(Basiron and Simeh, 2005)*. As results, Malaysia is facing a gigantic problem in disposing a palm oil fuel ash (POFA) which is a by–product of palm oil mill. Based on MPOB Economic and Statistic 2009, it has been reported that approximately 3 million tonnes of POFA was produced right through Malaysia in 2007. Thus, the enormous quantity of POFA produced may contribute to the environmental problem in future if not properly disposed.

Realizing the potential pozzolanic properties in POFA and with aims at reducing the potential environmental problems related with POFA, many researchers have attempted to develop the POFA as pozzolanic mineral admixture in concrete. It has been found that the well-processed POFA can be used as a supplementary cementing material for the production of concrete *(Safiuddin et al. 2010)* and also shows a excellent potential to withstand expansion coupled alkali-silica reaction in concrete *(Awal and Hussin 19997)* and resistance of concrete towards chloride attack (*Awal and Hussin 1999)*.

The utilization of POFA are not limited to the normal concrete, but also have been applied to the new type of concrete such as lightweight concrete *(Mat Yahya ,2003)* and high-strength concrete *(Sata et al 2004)*. POFA also can be used as the partial cement replacement in high performance concrete with the presence of superplastisizer to produce a economical high performance concrete with enhance durability *(Malhotra, 1999)*.

The use high performance concrete (HPC) in structures has begun to make an impingement in Malaysia. Normally, HPC is being used for buildings in aggressive environments, marine structures, highways bridges and pavement, tunnel, precast unit and etc. *(Mittal, 1999)*. HPC is design to give optimised performance characteristics for the given set of materials, usage and exposure condition *(Swamy 1996)* and must meet these criteria: high workability, high in compressive strength and also high in durability (*Mehta and Aitcin 1990)*.

Thus, the object of this study is to determine the effectiveness of POFA as a partial cement replacement in high performance concrete toward the compressive strength, water absorption and also toward corrosion resistance.

Keywords: high performance concrete, POFA, superplastisizer, pozzolanic material

1.2 PROBLEM STATEMENT

The study is proposed basically based on the problem that is currently being discussed in Malaysia, which is a disposal of a by-product of palm oil industry, POFA. Today, Malaysia is currently number one palm oil producer which predicted to produce 18 million tonnes or 42% of the world palm oil in 2020 *(Basiron and Simeh, 2005)*. In fact, based of Principles Statistics of Palm Oil Estates issued by MPOB, the number of production of fresh fruit bunches are increasing significantly every year which at the same time will increase the production of palm oil and its by-product. POFA is rarely utilised and normally dumped in an open field near the palm oil mills without any profitable return, thus causing an environmental pollution and health hazard *(Sumadi and Hussin 1995)*.

This study is also proposed due to the problem that caused by the cement itself. The emission of CO_2 from cement production is one of the factors of global warming. Approximately 0.7% up to 1.1 % of CO_2 is being emitted for every tone of cement production *(Sata et al 2010)*. The CO_2 emission by a cement industry consist of those element which are 50% from the calcinatiom of limestone, 40% from the combustion of the fuel in kiln and 10% from the transportation and manufacturing of a concrete *(Bosoaga et al 2009)*. Thus, the reduction of cement usage could be one of the wise steps to reduce the CO_2 which cause a nuisance to the environment.

1.3 OBJECTIVES OF THE STUDY

The objectives of the study are:

i. To determine the effect of POFA as a cement replacement in HPC toward compressive strength.
ii. To determine the effect of POFA as a cement replacement in HPC toward water absorption.
iii. To determine the effect of POFA as a cement replacement in HPC toward corrosion resistance

1.4 SCOPE OF STUDY

Scopes of this study include the following procedures:

i. The study focus on the compressive strength, water absorption and the corrosion resistance of the specimens.
ii. The size of POFA to be used as a partially cement replacement is 75 μm.
iii. The study will consist 4 sets of specimens which are control sample, 10% of POFA replacement, 20% of POFA replacement and 30% of POFA replacement.
iv. The specimens in cast using a mix proportion of previous study.
v. The specimens are water cured for the 7, 28 and 90 days.
vi. The test involved in this study will be conducted at FKASA Lab, UMP.

1.5 SIGNIFICANT OF STUDY

The study will serve at the good understanding on the effectiveness of the POFA as a partial cement replacement towards high performance concrete in terms of compressive strength, water absorption and corrosion. In addition, this study will be best solution in preserving good environment by reduction of Portland cement and also the utilization of POFA in the concrete mix.

CHAPTER 2

LITERATURE REVIEW

2.1 CONCRETE

Nowadays, concrete is the most widely used man-made construction material in the construction field either structure or infrastructure. The main usage of the concrete can be seen at building components such as columns, beams, roofs, floor slabs, foundation walls, footings and staircases. Apart from that, concrete also being used in construction of sidewalks, paving, highways, bridges and etc. Concrete is widely used due to its advantages such as easy to be cast and handle, economical, fireproof, watertight, and many more. In addition, concrete also have surface continuity and solidity which help to bond with other materials.

Casting of concrete start when first mixed the water and cement constitute a paste which surrounds all the individual pieces of aggregate to make a plastic mixture. Concrete normally changes from a plastic to a solid state in about 2 hours. There is a chemical reaction called hydration takes place between the water and cement which cause the concrete to harden. The demould process is carried out after leaving the concrete harden for 24 hours inside the mould. The specimen is then undergoing the curing process. Curing process is crucial in the process of producing a good concrete as the concrete will continues to gain strength as it cures.

Normally during the 7 to 10 days of curing, it is important to ensure that the concrete not be permitted to freeze or dry out. In practical terms, about 90% of its strength is gained in the first 28 days. The concrete compressive strength is depends upon many factors such as quality and proportions of the ingredients and also the curing environment.

2.2 LIMITATION OF CONCRETE

Concrete are only good at compressive strength but not in tensile strength. Thus, any concrete members which subjected to the tensile stress must be reinforced with the steel bars to prevent cracking and failure during construction.

Concrete also required a special supervised and a lot of precautions need to consider during casting. This is due to improper casting, handling and transporting process might cause cracking and other weaknesses in the structural that detract from the appearance, serviceability, and useful life of the concrete structure *(U.S. Department of Army, 1999)*.

2.3 HIGH PERFORMANCE CONCRETE

High Performance Concrete (HPC) is the concrete which meets special performance and uniformity requirements that cannot always be achieved by conventional materials, normal mixing, placing and curing practices *(Bharatkumar 2001)*. The use of HPC is in increasing demand in the construction field and is being seen as an good solution in the durability as well as the strength required for a unique and special structures *(Diah et al, 1992)*.

HPC is designed to give optimized performance characteristics for the given set of materials, usage and exposure conditions, consistent with the requirements of cost, service life and durability *(Swamy, 1996)*. The High Performance Concrete must meet these criteria: high workability, high in compressive strength and also high in durability *(Mehta and Aitcin 1990)*.

There is no necessary major change in the composition of the concrete in the process of producing the HPC. HPC is produce using the same basic ingredient as normal strength concrete, although the addition of admixtures and additive are needed to achieve the required results.

The major difference between conventional concrete and HPC is essentially the use of chemical and mineral admixtures *(Bharatkumar 2001)*. Use of chemical admixtures reduces the water content, thereby reducing the porosity within the hydrated cement paste *(Hover KC, 1998)*.

2.4 WATER/BINDER RATIO

Water/binder ratio of concrete is the single most important factor that influences the strength of concrete *(Blackledge G.F, 1975)*. Water/binder ratio is also used to affect the in the concrete. The water/binder used in this study is 0.28 which can be considered as low to achieve desired strength with assisted of presence of superplastisizer. A low water/binder ratio indicates the mix have a high paste content which shows a higher strength but lower workability compare to the higher water/ binder ratio and vice versa.

2.5 SUPERPLASTISIZER

High–range water reducing admixture, is also commonly known as a superplastisizer are normally used to significantly increase the workability of fresh concrete and also to reduce water requirement to produce high-strength concrete *(Maslehuddin et al, 1992)*. The reduction of the water/binder ratio will cause the production on a high-density cement matrix. The superplastisizer also might increase the compressive strength up to 90 days due to elimination of the capillary pores since there is no excess water.

With the used of superplastisizer, it is possible to reduce the amount of water content but yet able to produce same workability without affecting the strength of the concrete if the water/binder ration is kept constant *(Hover K.C, 1998)*. The influence of superplastisizer towards the workability of the concrete against the water content and development of early strength of concrete are illustrated as Figure 2.1.

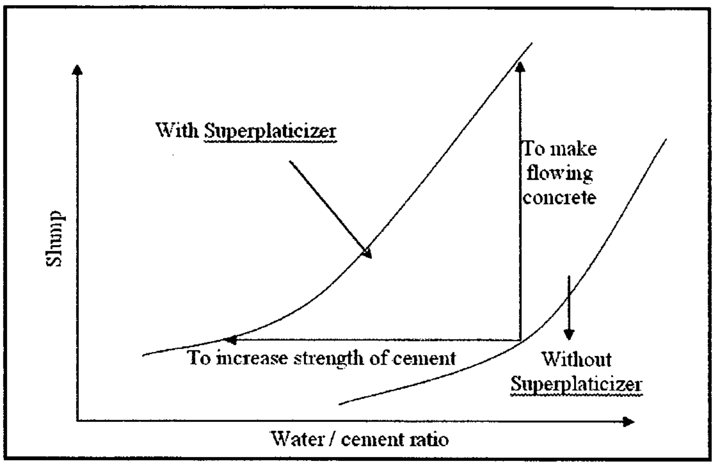

Figure 2.1: The influence of superplastisizer on the workability of concrete *(Neville and Brooks, 1987)*

There are three types of superplastisizer which are Lignosulfonate-based superplasticizers, Melamine sulfonate superplasticizers and Naphthalene sulfonate superplastisizer. Each of these superplastisizer has their own purpose and characteristic. The quantity of the superplastisizer to be used is normally determined by some sorts of trial and error procedure since there is no priori ways of identify the exact desired amount for a mix *(Diah et al, 2008)*.

2.6 PALM OIL FUEL ASH (POFA)

Palm oil industry is one of the major agro-industries in Malaysia. The raw materials in the form of fresh fruit bunches are supplied to the palm oil industry and it is process produces a large amount of solid waste material in form of fibers, shell, and empty fruit bunches. These solid waste materials were used as a fuel to produce steam for generating the electricity of the palm oil extraction process. Since the palm oil is one of the major raw materials used to produce bio-diesel, it is likely that the production of POFA increase every year *(Tangchirapat and Jaturapitakkul, 2010)*.

After the combustion, about 5% of palm oil fuel ash (POFA) by weight of solid wastes is produced *(Sata et al 2004)*. Due to the limited utilization of POFA, it has to be disposed as landfill materials, leading the potential future environmental problems.

Every ton of cement produces around 850kg of CO_2 emitted to the atmosphere, thus causing greenhouse effect *(Hendrik et al 2003)*.

These are the statistic issued by the Malaysian Palm Oil Board (MPOB) on the total planted hectarage of oil palm. Table 2.1 shows the statistic of the increment planted area by year. Thus, the production of POFA will also increases per year respectively.

Table 2.1: Principal Statistic of Oil Palm Estate,2000 - 2010

Tahun *Year*	**Bilangan Estet** *Number of Estate*	**Keluasan bertanam** *Planted area*	**Keluasan yang dituai** *Harvested area*	**Pengeluaran Buah Sawit** *Production of Fresh Fruit Bunches*	**Hasil bagi se Hektar** *Yield per Hectare*	**Harga Purata Penghantaran Tempatan** *Local Delivered Average Price*	**Jumlah Pekerja Bergaji yang Diambil Bekerja dalamTempoh Gaji Terakhir** *Total Number of Workers Employed During the last Pay Period*
		Hektar *Hectares*		**Tan metrik** *Tonnes*		**RM / tan metrik** *RM / tonne*	
2000	3,581	3,055,846	2,621,502	48,052,132	18.33	996.50	252,549
2001	3,622	3,155,670	2,663,610	50,981,495	19.14	894.50	265,182
2002	3,778	3,311,148	2,831,657	50,884,876	17.97	1,363.50	285,444
2003	3,877	3,414,042	2,915,902	55,373,112	18.99	1,544.00	314,658
2004	3,940	3,508,641	3,085,290	57,386,394	18.60	1,610.00	331,648
2005	4,078	3,626,801	3,212,804	60,657,740	18.88	1,394.00	329,709
2006	4,145	3,710,319	3,256,535	63,828,086	19.60	1,510.50	347,755
2007	4,259	3,834,758	3,320,100	63,181,503	19.03	2,530.50	509,831
2008	4,283	3,947,763	3,915,924	87,749,835	20.18	2,777.50	500,817
2009	4,317	4,082,124	3,477,438	66,766,810	19.20	2,236.50	502,229
2010*	4,370	4,202,381	3,565,321	64,282,738	18.03	2,701.00	446,368

There are many researchers found that POFA had pozzolanic properties and could be as a partial replacement of the concrete *(Sata et al 2004)*. The study of palm oil fuel ash was started by Tay JH on 1990, which used it to replace Portland cement with 10% up to 50%. He found that the range of 20% - 50% of cement replacement, the decrease in the compressive strength of the concrete at various ages was almost proportional to the amount of ash in the concrete mixture, except when only 10% POFA was used.

Then, another study is conducted to determine the compressive strength of the concrete containing POFA *(Awal and Hussin, 1996)*. The results revealed that it is possible to use 40% of POFA as a partially cement replacement without affecting its compressive strength. The maximum compressive strength gain occurred at a replacement level of 30% by weight of cement. Nonetheless, it also revealed that POFA has a good potential for cater expansion due to alkali-silica reaction *(Awal and Hussin, 1997)*. The utilization of POFA also observed to improve the resistance of concrete to chloride ion penetration *(Awal and Hussin, 1999)* , increase resistance to acidic environment *(Tay, 1990)* and improve sulphate resistance of concrete *(Tangchirapat, 2007)*.

There are also researches related on the effect of fineness of POFA. It is reported that the compressive of mortar containing original unground POFA was low due to the large particle size and high porosity of POFA *(Sukantapree et al 2002)*. The fineness of POFA also contributes to the rate of hydration and the pozzolanic reaction. Furthermore, another study have identified that POFA with high fineness has a highly pozzolanic reaction which can be used as a supplementary cementitious material for producing the high strength concrete *(Sata et al 2004)*.

The particle shape of POFA also needs to be considered. There is a major different in the particle shape between unground POFA and ground POFA. Figure. 2.2 shows example of unground POFA which is large, rounded in shape and porous compared to Figure 2.3 which shows the ground POFA that have irregular and angular shape. Angular and irregular particle shape have more exposed surface which will enhance and increase the interfacial bonding between particle compared to the rounded surface. The higher strength might be produce as the bonding between grounds POFA is stronger.

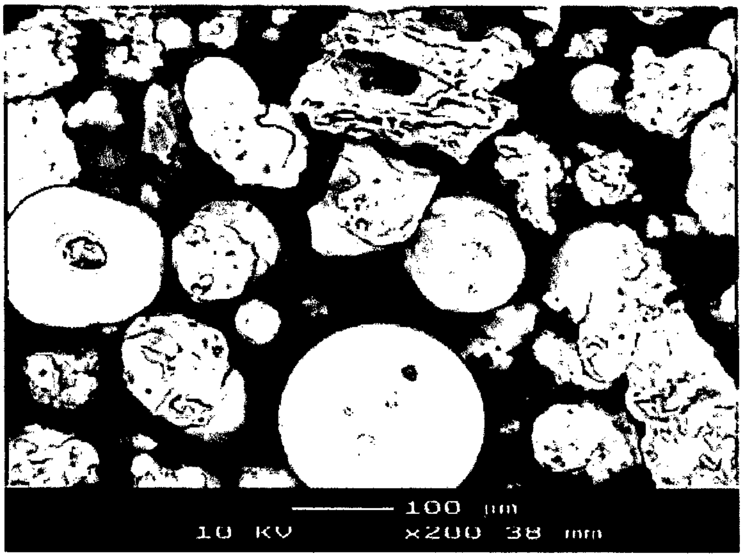

Figure 2.2: Unground POFA *(Jaturapitakkul et al, 2007)*

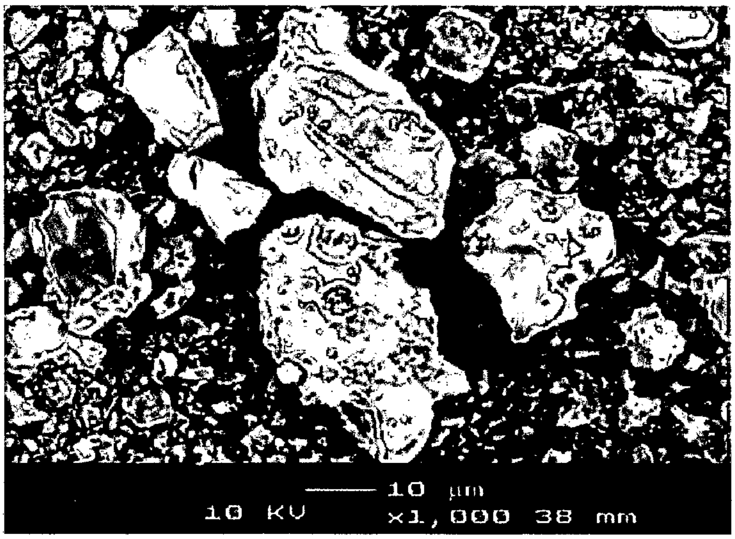

Figure 2.3: Ground POFA *(Jaturapitakkul et al, 2007)*

2.7 POZZOLANIC MATERIAL

Pozzolan is a siliceous or alluminious material, which in itself posses little or no cementitious value but will finely divided form and in the presence of moisture, chemically react with calcium hydroxide $Ca(OH)_2$ to form compounds possessing hydraulic cementatious properties. There are three major factors that affect the activity of pozzalans which are the finess of its particle, the degree of amourpheness of its structure and the SiO, Al_2O_3 and Fe_2O_3 content.

According to the ASTM C618-04, the mineral admixture can be classified to the 3 type of class which is Class N, Class F and Class C as in Table 2.2. Basically; the classification of the pozzolanic ashes depends on its chemical composition of the material itself.

Table 2.2: Requirements for an Acceptable Quality of Pozzolan

	Natural	**Class F**	**Class C**
Fineness (max. % retained when wet sieved on 45 mm sieve)	34%	34%	34%
Strength Activity Index	75	75	75
Min "SiO_2+Al_2O_3+Fe_2O_3"	70	70	50

Silicon dioxide (SiO_2) and aluminum trioxide (Al_2O_3) contents in pozzolanic material react with calcium hydroxide ($Ca(OH)_2$) to produce CSH, C_2ASH_8 and C_4AH_{13} *(W. Kreohong et al 2011)*. Most researchers have studied $Ca(OH)_2$ in cement paste containing pozzolanic material by thermo gravimetry (TG). The $Ca(OH)_2$ content is reduced with increasing replacement of pozzolanic material and fineness *(Chindaprasirt 2007)*. It also found that the reduction of the $Ca(OH)_2$ content indicates consumption in the pozzolanic reaction *(Barbhuiya et al 2009)*. In addition, the use of pozzolanic material to partially replace cement reduces the $Ca(OH)_2$ content in concrete, which could improve the sulfate resistance of the concrete. Furthermore, there is another study which used differential thermal analysis (DTG) to determine the hydration products involved and explained the increase in the compressive strength of paste *(Chaipanich and Nochiya, 2010)*. They also found that blended cement paste can reduces the amount of $Ca(OH)_2$ content while the mass loss of ettringite, C–S–H and C_2ASH_8 increases when the curing time is increased.

POFA is one of the agro waste ashes whose chemical composition contains a large amount of silica and that has high potential to be used as a cement replacement (Tangchirapat et al, 2003). However, the use of POFA as a pozzolanic material for partially replacing Portland cement is not well known and little research has been conducted. Previous study already used ash from palm oil waste to replace portland cement and showed that it had low pozzolanic properties, and recommended that POFA should not be used as a cement substitute in any quantity higher than 10% by weight of binder *(Tay, 1990)*. The low pozzolanic property of palm oil fuel ash is due to the large particles and porous structure, and thus its use results in a very low rate of pozzolanic reaction. Later, there are many researchers showed that POFA can be successfully used as a supplementary cementing material in concrete due to its good pozzolanic property *(Awal and Hussin, 1997)*.

2.8 FINENESS OF POFA

Fineness of POFA does give an effect toward the result of the study. In this study, POFA will be grind for 8 hours to ensure that it will have a smaller particle size. This is because the compressive strength of concrete decreased for the ungrounded POFA content in the range of 20-50% as in Figure 2.4 *(Tay and Show, 1995)*.

The decrease in the compressive strength of concretes unground POFA was due to the large POFA particles with high porosity. The porous POFA particles increase the actual water/binder ratio in concrete due to the absorption of water, and thus results in a lower compressive strength *(Jaturapitakkul et al. 2007)*.

Ground POFA gives a good effect on the concrete. With its finer size, POFA can act as a micro-filler and increase the compressive strength of concrete. It is found that concrete containing 10-30% of ground POFA will exhibit a higher compressive strength the OPC concrete at 28 days as in Figure 2.5 *(Tangchirapat et al, 2009).*

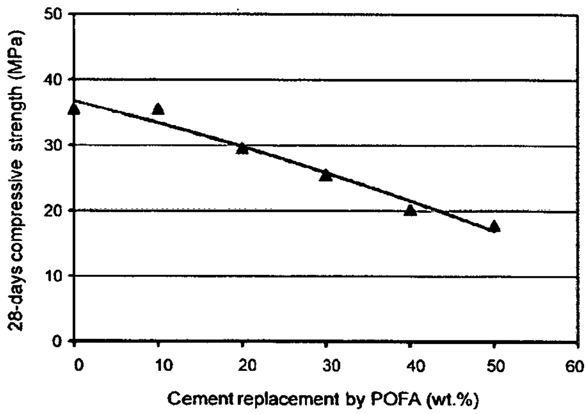

Figure 2.4: Effect of unground POFA on the compressive strength *(Tay 1990)*

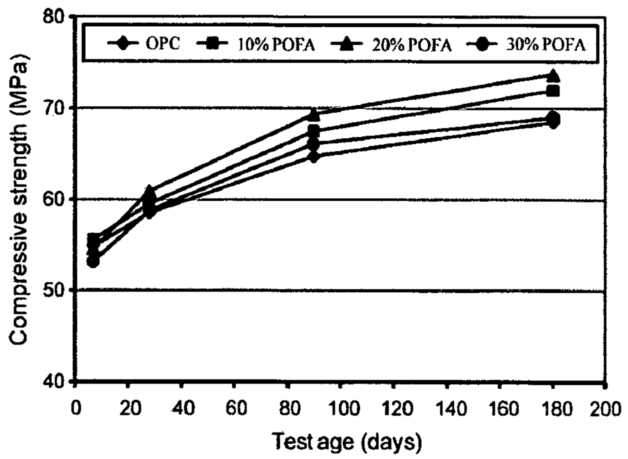

Figure 2.5: Effect of ground POFA on the compressive strength *(Tangchirapat et al, 2009)*

2.9 CHEMICAL COMPOSITION OF POFA

POFA is a pozzolanic material in term of both physical properties and chemical analysis. This pozzolanic material can be classified as Class C, Class N, of Class F as specified in ASTM C618-92a, 1994. POFA is basically a substance that is moderately rich in silica content but very low in lime content as compared to the OPC *(Awal and Hussin, 1997)*. The chemical composition of POFA is varied due to operating system in different palm oil mill.

2.10 COMPRESSIVE STRENGTH

Nowadays, the ground POFA are not limited to the normal concrete but also being used in a special concrete such as high performance concrete, aerated concrete and also high strength concrete *(Awal and Hussin, 1999)*. The optimum ground POFA to be used in concrete to satisfy the desired high strength is 20% *(Chindaprasirt et al, 2007)*.

The ground POFA provides much higher compressive strength compare to the unground POFA due to the particle size and fineness. This can be explained by the ground POFA particles will filled up the micro-voids between the cement particles due to smaller particle size *(Isaia et al, 2003)*. The POFA micro-filling ability is a major contribution of the high strength of concrete.

Concrete that consist of ground POFA will exhibit lower compressive strength at the early age (<7days) due to the slow pozzolanic activity of the ground POFA *(Tonnayopas et al, 2006)*.

2.11 DURABILITY

Concrete specimen that consist of POFA in the mixture will exhibits much better resistance to attack by chloride ions and acid solution *(Awal and Hussin, 1999)*. This is due to pozzolanic behavior itself for the excellent performance against such aggressive environment and also play an effective role in producing strong and highly durable concrete *(Tay, 1990)*.

The durability test to be conducted in this study is water absorption test and corrosion resistance test. The water absorption of POFA concrete is reduced as the there